TT Transform attributes enhancing seismic interpretation: a case of thin turbidites reservoirs in the Santos Basin, offshore Brazil

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Summary

The seismic interpretation of thin turbiditic sandstones, especially when intercalated with siltstones and shales, is challenging and imposes difficulties for exploration, reservoir delimitation, and hydrocarbon production. One of the most significant problems in this environment arises from seismic resolution, which is typically unable to resolve thicknesses below 10-20 meters. This situation is evident in the post-salt section of the Brazilian offshore basins. To address this issue, we enhanced the seismic resolution using the TT transform, combining local frequency, phase, and magnitude components. Compared to conventional seismic attribute results, the TT Transform's attributes enabled us to identify depositional turbiditic elements within the turbidite system, as described in the literature and adopted as a conceptual model. By using this combination, we developed accurate architectural models that incorporate wellbore information. From these outputs, it is possible to construct reliable geological models, allowing the asset team to manage the inherent uncertainty and improve the project's profitability.

Introduction

In hydrocarbon exploration, delimitation and production focused on turbidite reservoirs, identifying and mapping the architecture of depositional elements present in these systems play a crucial role in delineating the best reservoir facies. This process supports the construction of detailed geological models and guides drilling strategies for producer and injector wells that maximize the profitability of exploiting these reservoirs. Mutti and Normark (1991) define depositional elements as the fundamental building blocks of turbidite systems. The architecture of each of these reservoir elements is determined by the interaction among sedimentary processes, seafloor morphology, and the distribution of sediment grain sizes (Mutti and Normark, 1991; Posamentier and Kolla, 2003).

To enhance the visualization and interpretation of these geological features throughout seismic data, seismic attributes are routinely used (Chopra and Marfurt, 2007). The extraction or calculation of these attributes is fundamental for the detailed seismic interpretation process, allowing geoscientists to identify patterns in the data that may relate to physical properties of interest, such as depositional or structural features. However, the reservoir intervals to be interpreted are often below the seismic data resolution limit or have their amplitude signal significantly affected by bright spots anomalies (Chopra and Marfurt, 2007). That is the case of our study area, located in the northeast of Santos Basin, Brazilian offshore. The turbidite reservoir section belongs to a Campanian age sequence (Moreira et al., 2007) and consist of very fine to fine-grained sandstones interbedded with siltstones and shales. We selected two intervals to work with, denominated Zone 1 and Zone 2 (Figure 1). The turbiditic sandstones located in Zone 1 are oil and condensate producers, while those in Zone 2 contain gas.

To perform seismic interpretation in a geological context such as that described, attributes that decompose the seismic signal into intrinsically many frequency components have emerged as essential tools (Partyka et al., 1999). This includes spectral decomposition techniques, and the frequency, phase and magnitude components generated from the time-time (TT) Transform (Matos and Marfurt, 2022). The TT Transform, initially presented by Pinnegar and Mansinha (2003), is a time-time representation based on the short-window Fourier transform and the S transform that can enhance seismic resolution (Matos and Marfurt, 2022). The last authors also used this transform to generate seismic attributes from frequency and phase components. The TT transform attributes can highlight various depositional characteristics of an area that are not so obvious using conventional seismic/attributes data visualization.

The present research shows that enhancing the seismic resolution and adopting the TT Transform attributes allowed us to identify and interpret various geological features not detected before in this turbidite reservoirs. Such features make it possible to correlate the mapped geometries with information obtained from the log analysis of already drilled wells in the selected area. Understanding and interpreting the architecture of these reservoirs not only aids in exploring these fields but also drives efficient reservoir delimitation and exploitation, significantly contributing to the advancement of geological characterization techniques for complex sedimentary systems.

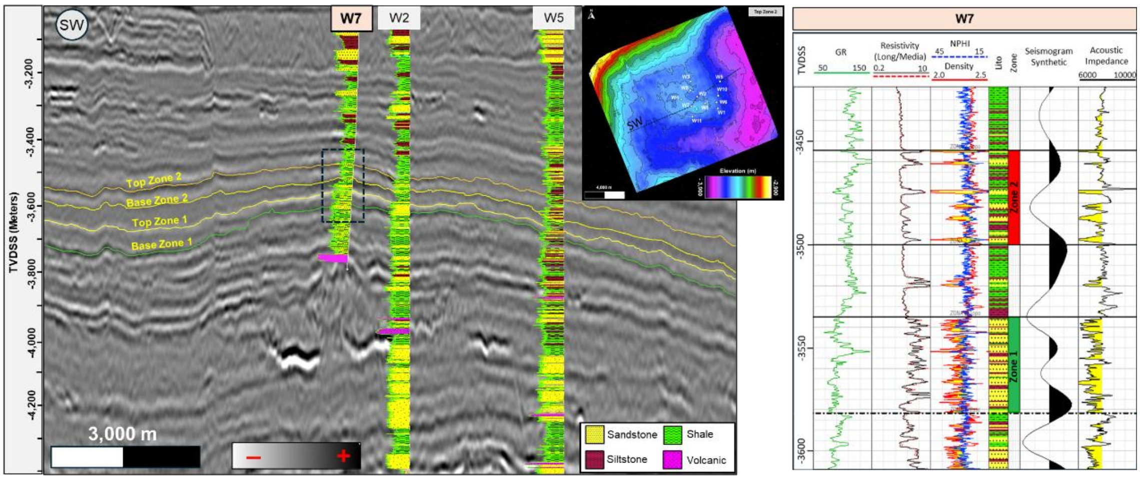

Figure 1: Seismic strike section showing the interpretation of top and base horizons for the two zones defined in this study. Detail of the well W7, illustrating the petrophysical and thickness characteristics of the turbidite reservoirs present in the area.

Methodology

We evaluated conventional seismic attributes of the PSDM volume to provide a rapid visualization of the study area's geological characteristics and to compare them with the TT-transform ones. We selected the following attributes: Amplitude Envelope, Root Mean Squares (RMS) Amplitude, Instantaneous Frequency, Instantaneous Phase, and Coherence. Maps of the instantaneous and RMS values for the top and base surfaces of Zones 1 and 2 were extracted.

The TT Transform generates volumes that show an increase in high-frequency ranges, enhancing its usable bandwidth. Its inherent components of magnitude, frequency, and phase were also extracted. To improve the visualization of these attributes on a map, a co-rendering of the frequency and phase components over the magnitude was performed, applying an opacity filter to the latter to highlight its higher values (greater amplitudes of the data). These maps are then compared to the amplitude maps to emphasize the various geometries related to the depositional elements present in the area, which were not well visualized by conventional attributes.

Finally, interpretations of the depositional features for the top and bottom surfaces of Zones 1 and 2 were performed using the TT Transform attributes maps along the petrophysical information obtained from the well's logs. Therefore, it was possible to propose an evolutionary depositional model for this turbidity system.

Results

The first observation when comparing the co-rendered maps of frequency components and magnitude, with the Instantaneous Amplitude maps, is the number of geological features that were not clearly visualized before through conventional seismic attributes. A good example is in the region of structural high on the Zone 1 top surface, where the amplitude maps appear more blurred due to the bright spots effect. On the frequency component's map, features such as feeder channels, distributary channels edges and lobes complex, stand out (Figure 2). Another important detail is the presence of the lobe complex drilled by wells W1 and W6 (red/black colors in the southeast of the area), which did not appear on the amplitude map. That was possible due to the increase in the frequency range obtained by the Transform TT.

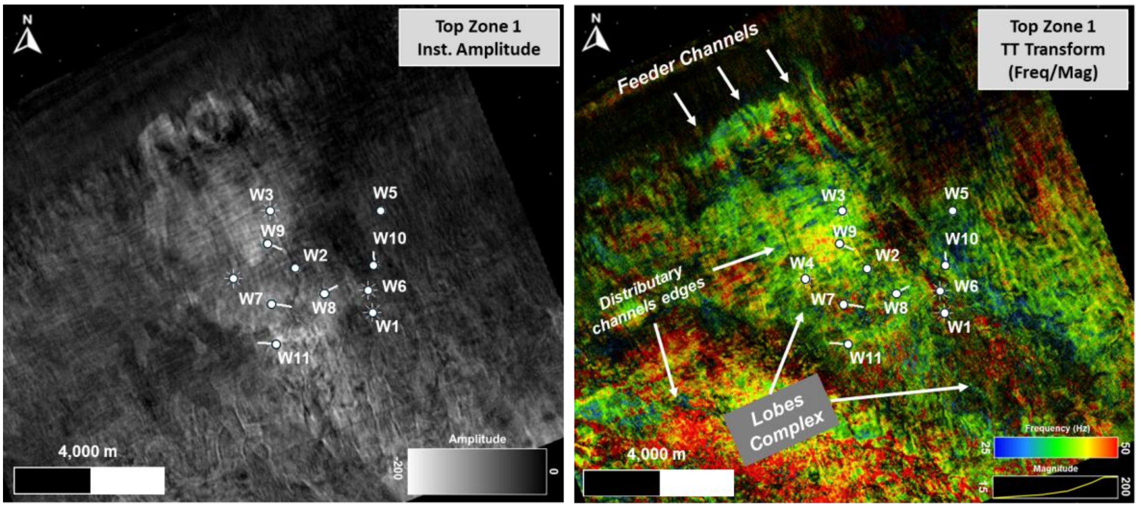

Figure 2: Comparison of the Instantaneous Amplitude map (left) and TT Transform' co-rendered frequency components and magnitude (right), for the top Zone 1 surface.

Based on the results generated by the components of the TT Transform attributes maps for the base and top surfaces of Zones 1 and 2, along with information from the structural, isopach maps and well's logs, the depositional elements geometries of the turbidite system present in the study area were interpreted. The contouring of the mapped bodies was based on the lobe complex geometry. The feeder channels and terminal lobes of the turbidite system were contoured. In some areas, distributary channels within the lobe complex are also visible. A general pattern observed for the study intervals is a region where a complex of amalgamated feeder channels predominates, with a depositional direction toward the SE, in a physiography of base slope, and a complex of terminal lobes, also amalgamated, occurring in a basin area, with lobe widths ranging from hundreds of meters to a few kilometers, mainly in the well's area. These bodies are difficult to distinguish and individualize on the maps, although the TT Transform' attributes highlight many. Two size scales were defined for the identified lobe complexes geometries: *Lobe Complex* and *Larger Lobe Complex*. The Lobe Complex area occurrence was denominated *Lobe Complex Set*. A possible area of reworking by contour currents was also identified.

Figure 3 presents the proposed depositional evolution model for the turbiditic system in the research area, based on interpretations made for the surfaces corresponding to the base and top of Zones 1 and 2, derived from TT Transform's attributes, structural maps, and isopach. It is noticeable from the deposition sequence shown in the maps, the presence of a retrogradation pattern, already observed in the well's log analysis, with the retreat of turbiditic system towards the coastline and a reduced number of feeder channels and terminal lobes.

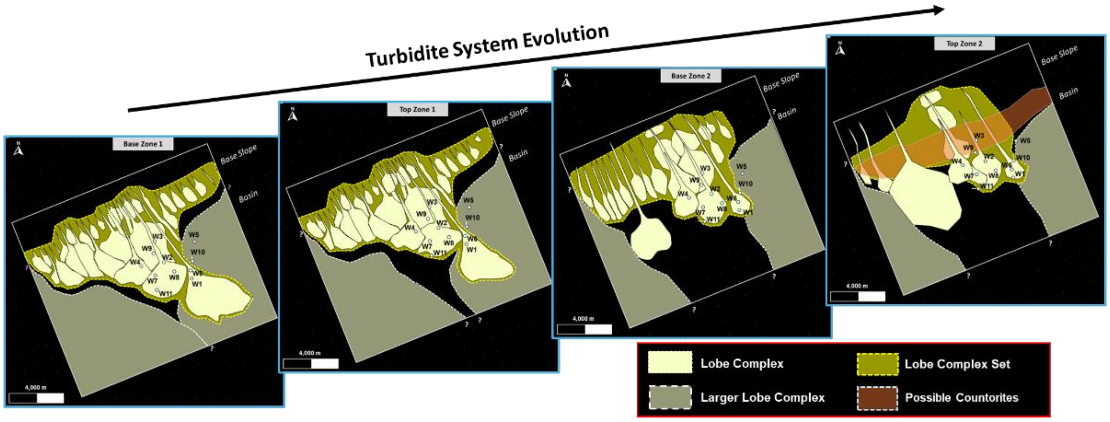

Figure 3: Proposed depositional evolution model for the turbidite system, based on the results generated by the components of the TT Transform attributes maps.

Conclusions

The present study demonstrated that using only amplitude or other conventional attributes does not reveal all the geological information necessary to build a detailed reservoir model, especially when there are issues such as layers below seismic resolution, significant intercalation with shales and siltstones, and the presence of bright spots in oil and gas accumulation regions. This situation applies to the two intervals selected for this research. The technique of attribute generation using the TT Transform considered frequency, phase, and magnitude components. Compared to the maps extracted from conventional attributes, particularly amplitude, we observed that the frequency and phase components co-rendered with the magnitude from the TT Transform yielded better results regarding resolution and the images generated for interpreting the turbiditic system of the two studied zones. This is because they enhance the magnitude of high-frequency components, improving the visibility of intervals and lineaments at the limits of seismic resolution.

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